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Assessing Worker Exposures during Composite Material and Fiberglass Repair: A Special Report for Bioenvironmental Engineers

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14. ABSTRACT
This revised special report updates and supersedes the 1999 report published as document number IERA-RS-BR-TR-1999-0010. There continues to be a significant increase in the use of composite materials in the Air Force with each new aircraft. Along with increased use of composites, there is an increase in composite repair activities in the Air Force. A series of field evaluations was conducted at Charleston Air Force Base (AFB), Robins AFB, Hill AFB, McClellan AFB, Eglin AFB, Hurlburt AFB, Cherry Point Naval Aviation Depot (in a joint effort with the Navy Environmental Health Center), and the joint Air Force/Navy Aircraft Structural Maintenance School at Pensacola Naval Air Station. This updated special report summarizes the recommended sampling methodology, data interpretation, ventilation requirements, personal protective equipment, and workplace practices for advanced composite material and fiberglass repair, based upon the original sampling results from the Institute of ESOH Risk Assessment field evaluations.

15. SUBJECT TERMS
Composites, advanced composite materials (ACM), fiberglass, structural maintenance, aircraft battle damage repair (ABDR), IERA-RS-BR-TR-1999-0010

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SUMMARY OF CHANGES FROM IERA-RS-BR-TR-1999-0010

This revised special report updates and supersedes the 1999 report published as document number IERA-RS-BR-TR-1999-0010. Changes include significant updates to style and formatting throughout the report. A summary of specific changes is as follows:

- Section 1.0 Introduction reworded and expanded to retain currency.
- Section 2.0 Occupational and Environmental Exposure Limits (OEELs) added.
- Paragraphs 2.1–2.3 added to update with information to retain currency and correctness and improve upon the content of the original document. Paragraph 2.2 explains the departure from using 1.0 f/cc for composite fibers with the exception of fiberglass.
- Paragraph 3.2.4 Damage Removal/Scarfing added to describe and expand a process between Clean Wiping and Core Repair.
- Paragraphs 3.3.4 & 4.3.5 and several tables updated or removed that detailed sampling protocol for hazards tertiary to composite material processes. The latest sampling protocols is available in the USAFSAM Laboratory Sampling Guide.
- Paragraphs and associated tables updated the recommended occupational and environmental exposure limit for a number of chemical hazards (e.g., inhalable particulates not otherwise specified, graphite, boron, and aramid fibers).
- In Aircraft Battle Damage Repair (ABDR), "Disclaimer" section deleted.
- A list of Abbreviations and Acronyms added.

1.0 INTRODUCTION

Composite materials are macroscopic combinations of two or more materials. Composites have existed for a very long time; for example, the ancient Egyptians added chopped straw into clay to make bricks stronger. Generally, the term “composites,” as used in the Air Force, refers to fibers in a polymer matrix. The first application of composites in military aircraft was at the end of World War II, when radomes were fabricated by the wet lay-up of glass fibers woven into a cloth and impregnated with a polyester resin. In the 1960s, very strong and stiff ceramic, boron, and carbon fibers became available. The term “advanced composites” describes composite materials made from these fibers [1]. Since then, the use of composite materials on Air Force aircraft has significantly increased, and presented in Table 1, their use has increased as new weapon systems are fielded [2].

Table 1. Composite Material Composition of Selected Military Aircraft

Aircraft Type	Percent Composite Material by Weight
F-15	2
C-17	8
F-16	13
B-2	37
F-22	38

Along with the increased use of composites, there is an increase in composite repair activities in the Air Force. The first version of this guide initiated assessments in the late 1990s in response to the Structural Maintenance community’s concern regarding inconsistencies in protective equipment requirements from base to base. At that time, the Air Force Research Laboratory's Advanced Composites Support Office (ACSO) routinely found inconsistencies in engineering controls and protective equipment among composite repair facilities throughout the Air Force. As a result of those concerns, the ACSO requested the Industrial Hygiene Branch of the Air Force Institute for ESOH Risk Analysis (IERA) (the predecessor of the Consultative Services Division (OEC) of the U.S. Air Force School of Aerospace Medicine [USAFSAM]) to evaluate composite repair operations in the Air Force. IERA’s goal was to recommend appropriate engineering controls and protective equipment to standardize procedures and reduce worker exposures. IERA conducted a series of field evaluations at Charleston Air Force Base (AFB), Robins AFB, Hill AFB, McClellan AFB, Eglin AFB, Hurlburt AFB, Cherry Point Naval Aviation Depot (in a joint effort with the Navy Environmental Health Center), and the joint Air Force/Navy Aircraft Structural Maintenance School at Pensacola Naval Air Station. This updated special report summarizes the recommended sampling methodology, data interpretation, ventilation requirements, personal protective equipment (PPE), and workplace practices for advanced composite material (ACM) and fiberglass repair, based upon the original sampling results from IERA’s field evaluations found in Appendices A, B, and C.

In addition to the ACM and fiberglass repair evaluations performed, the Aircraft Battle Damage Repair (ABDR) Program Management Office requested an evaluation of ABDR composite repair operations in the Air Force. Specifically, IERA asked USAFSAM/OEC to recommend appropriate protective equipment and engineering controls to standardize procedures

and reduce worker exposures. IERA tasked USAFSAM/OEC to determine whether the ground crew ensemble and protective mask provide adequate protection when performing ABDR operations during training for nuclear, biological, and chemical environments. To answer these questions, field evaluations of ABDR operations were completed at Tinker AFB, McClellan AFB, and Hill AFB. Sampling results from these field evaluations are in Appendix C. The last section of this special report summarizes the recommended sampling methodology, data interpretation, and PPE requirements for ABDR composite repair operations. However, before presenting the evaluation and control of composite hazards, it is important that the reader understands what occupational exposure standards govern composites and to what exposure limits airborne composites must be controlled.

NOTE: This revised special report updates and supersedes the 1999 report published as document number IERA-RS-BR-TR-1999-0010. In this special report, the term “composite repair” is meant to include both ACM and fiberglass repair operations. A separate special report, *Assessment of Composite Material Hazards at Crash Sites: Industrial Hygiene Guidance for Bioenvironmental Engineers*, covers emergency and accident response measures.

2.0 OCCUPATIONAL AND ENVIRONMENTAL EXPOSURE LIMITS (OEELs)

2.1 Unchanged Exposure Standards

Occupational and environmental exposure limits (OEEL) are the Air Force-specific exposure levels used by Bioenvironmental Engineering Flights (BEFs) to describe an exposure limit and control health risk. The OEELs are commonly adopted from established recognized standards (when possible), such as the Occupational Safety and Health Administration (OSHA) permissible exposure limits (PELs), the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit values (TLVs), or a limit noted in an Air Force Occupational Safety and Health Standard or Air Force Instruction. In the 1999 report titled *Assessing Worker Exposure during Composite Material Repair: Industrial Hygiene Field Guidance for Bioenvironmental Engineers*, the authors recommend using the *particulate not otherwise specified (PNOS)* standards for airborne composite hazards. As of March 2014, the current PNOS standard’s values have not changed from those published in the original report. The approach for comparing composites to PNOS is also consistent with the National Institute for Occupational Safety and Health’s (NIOSH) health hazard evaluations of composite material hazards [3]. USAFSAM maintains the recommendation for comparing composite material exposures to the PNOS OEEL, so long as the following ACGIH Appendix B criteria still apply for the particulates:

1. do not have an applicable TLV (or other OEEL);
2. are insoluble or poorly soluble in water (or aqueous lung fluid); and
3. have low toxicity (i.e., are not cytotoxic, genotoxic, or otherwise chemically reactive with lung tissue, and do not emit ionizing radiation, cause immune sensitization, or cause toxic effects other than inflammation or the mechanism of “lung overload”) [4,5].

2.2 Updated Exposure Standards

While the gravimetric PNOS standard is remaining unchanged as the OEEL for composite materials, there is a significant change regarding the fiber per cubic centimeter (f/cc) OEEL. The previously mentioned 1999 report included an 8-hour time weighted average (8-h TWA) OEEL of 1.0 f/cc for all types of composite fibers “by analogy to synthetic vitreous fibers,” e.g., the fiberglass OEEL. In essence, this promulgates a blanket comparison of all composite fibers to the fiberglass standard of 1.0 f/cc. Controlling occupational exposures of all composite compositions to the fiberglass standard is neither supported in peer-reviewed literature, nor a regulatory guidance. While fiberglass is a specific type of composite material, it is the only type for which there is a standard measured in f/cc. All other composites are measured using a gravimetric sample analysis and reported in milligrams per meter cubed (mg/m^3). Table 2 presents the recommended exposure limits for composite material during repair and maintenance operations [4-6].

Table 2. Exposure Limits for Substances Encountered during Composite Material Repair

Composite Material	8-h TWA	
	ACGIH TLV (mg/m^3)	OSHA PEL (mg/m^3)
Graphite (all forms except graphite fibers) Note: Respirable particulates only	2.0	5.0
All Other Respirable Composite Materials (i.e., aramid, boron, carbon, or combination)	3.0	5.0
All Other Inhalable Composite Materials (i.e., graphite, aramid, boron, carbon, or combination)	0.0	15.0
Continuous Filament Glass Fibers (i.e., fiberglass)	1.0[a]	-.-

[a]Units f/cc.

3.0 ADVANCED COMPOSITE MATERIAL REPAIR ACTIVITIES

3.1 Description of Advanced Composite Materials

Composite materials consist of a reinforcing fiber and a resin. The fibers within composites are the load-bearing elements, while the resin molecules fill the voids and transfer the stress from fiber to fiber [7,8]. Composite materials are “advanced” if they combine the properties of high strength, high stiffness, low weight, corrosion resistance, and, in some cases, special electrical properties. ACMs are used in aircraft because they have a higher strength-to-weight ratio than metal components [Warnock R. Advanced Composite Program Office. Personal communication; 1998 Apr]. The most common advanced composite systems found on aircraft include aramid fiber/epoxy resin, boron fiber/epoxy resin, carbon fiber/epoxy resin, and graphite fiber/epoxy resin [Swope M. USAF Advanced Composite Program Office. Personal communication; 1998 Jul] (DuPont manufactures aramid fibers under the brand name Kevlar®). An ACM typically consists of a honeycomb core sandwiched between two laminates. This laminate is several layers of resin-impregnated fiber stacked to maximize the material strength

[Hakim A, Warnock R. Advanced composites aerospace structures repair class; 1998]. For the purpose of discussion within this report, the definition of ACM does not include fiberglass, which is discussed separately in section 4.0 Fiberglass Repair.

3.2 Process Description

Workers perform ACM repair on aircraft parts that are usually removed from the aircraft then repaired in a composite repair or structural maintenance facility. Technicians occasionally make repairs while the parts are still on the aircraft. ACM repair operations vary across the Air Force as Structural Maintenance shops use different tools, techniques, and ventilation systems. However, the repair operations usually consist of the following sequential procedures [9-12]. Step-by-step descriptions of these processes can be found in Technical Order (T.O.) 1-1-690, *General Advanced Composite Repair Processes Manual* [13].

3.2.1 Damage Assessment. Assessment of composite material damage of parts identified for repair. The worker may identify the part for repair because of a nick, gouge, or cut in the painted surface, or by a broken or missing piece of composite material from the part. Workers perform the assessment by visually inspecting the part, or by using a coin or tap hammer on the part to determine areas of delamination, and marking the area for repair with either masking tape or a marker. Instrumented inspection techniques such as x-ray, ultrasonics, shearography, or thermography are also used.

3.2.2 Depainting. Mechanical removal of coatings from the aircraft part surface. Also called scuff sanding, this procedure removes the topcoat and primer to expose the ACM. Workers depaint the parts with a pneumatic rotary right angle grinder, straight grinder, rotary dual action sander, or an orbital sander. Mechanical abrasion generates inhalable particulates and possible chromate exposures if the primer coating contains strontium, zinc, or lead chromate.

3.2.3 Clean Wiping. Removal of dust, dirt, and oil from depainted surfaces. After depainting, residual dust is present on the part. After removing the majority of the dust by brushing, the worker wipes a solvent on the part with a clean rag. Several different solvents are available, including methyl ethyl ketone, acetone, or isopropyl alcohol; the most common solvent is isopropyl alcohol. The procedure normally takes less than 10 minutes, but the time devoted to clean wiping depends on the size of the surface area the worker is cleaning. Exposures result from solvent vaporization, but are usually limited due to the brevity of the operation.

3.2.4 Damage Removal/Scarfing. Mechanical removal of damaged ACM and chamfering of the laminate. Also called grinding, this procedure removes small quantities of damaged composite material so the workers can apply a flush patch. Proper scarfing exposes each layer of the laminate; the layers appear as concentric circles around the center of the damaged area. Workers usually scarf with either a pneumatic rotary straight or right angle grinder, such as the Dotco®, and may attach 1-, 2-, and 3-inch grinding discs to the grinders. The most common grit size to use for scarfing is 80, although workers may use other grits depending upon the ACM of interest. Inhalable and respirable particulate exposures may occur; the ACM may release a small number of fibers.

3.2.5 Core Repair. Rebuilding or filling in damaged areas of the honeycomb core material. The worker may need to fill in the existing core with an epoxy-based compound to improve its strength if the core material is damaged in addition to the overlaying laminate. Occasionally, the core material is damaged beyond repair and must be completely replaced. The worker replaces the core material by cutting a section from the damaged core and installing a new section of honeycomb material using an epoxy-potting compound. Worker skin exposures to unreacted epoxy and amine compounds may occur while the potting compound is mixed and applied.

3.2.6 Lay-Up. Designing, cutting, and stacking of ACM cloth to form a laminate or patch. There are two types of lay-up operations: wet lay-up and pre-preg lay-up. In wet lay-up operations, a resin, usually epoxy-based, is mixed with a hardener, usually amine-based. This mixture is applied to an advanced composite cloth material, which is cut and stacked to form a laminate. In pre-preg lay-up, the ACM cloth is already pre-impregnated with a resin and hardener. The pre-preg material is cut and stacked to form a laminate, then attached to the scarfed area using a film adhesive. The resin systems present a skin contact hazard to personnel from the uncured epoxy and amine groups.

3.2.7 Curing. Solidifying the laminate by placing it under heat and pressure. Workers place the laminate underneath a vacuum bag to ensure a uniform pressure is applied. The laminate cures in an autoclave, beneath a heat blanket, or under heat lamps. There is little potential for exposures to personnel during curing due to the use of the vacuum bagging technique.

3.3 Air Sampling Methodology

During advanced composite repair operations, workers can be potentially exposed to particulates, chromates, solvent vapors, and uncured epoxy and amine groups. This special report only focuses on the particulate hazards directly from the composite material; however, a comprehensive exposure assessment should evaluate the unique hazards associated with each of the sub-processes during repair. Table 3 summarizes inhalable and respirable air sampling recommendations.

Table 3. Recommended Sampling Methodology for Advanced Composite Material Repair

Operation	Substance	Sampling Method	Sampling Media	Sampling Flowrate (lpm)
Depainting, Scarfing, Sanding, or Grinding Processes	PNOS, Inhalable	NIOSH 0500	Preweighed, 5.0-µm PVC, 37-mm cassette	2.0
	PNOS, Respirable	NIOSH 0600	Preweighed, 5.0-µm PVC, 37-mm cassette with cyclone	1.7 (nylon) 2.5 (aluminum)

Note: lpm = liters per minute; PVC = polyvinyl chloride.

3.3.1 Particulates. Particulates generated during advanced composite repair procedures vary in size and form a particulate mass distribution. There are four types of particulate distributions: the total aerosol mass, the inhalable particulate mass, the thoracic particulate mass, and the respirable particulate mass [4,5]. These distributions are based upon the aspiration and deposition characteristics of the human respiratory tract. The primary size distributions of interest during advanced composite repair are the inhalable and respirable mass distributions. The inhalable mass is the portion of the total aerosol mass the worker actually breathes into the respiratory tract, while the respirable mass is that portion of the total aerosol that ends up in the gas-exchange region of the lungs.

3.3.2 Inhalable Particulates. Three inhalable aerosol samplers are widely available, including the Institute of Occupational Medicine (IOM) sampler, the button sampler, and the conical inhalable sampler. SKC, Inc. distributes the IOM and button samplers and BGI, Inc. distributes the conical inhalable sampler. The IOM sampler is the most well known of these three samplers. The IOM sampler uses a 25-mm filter placed inside a removable cassette with a 15-mm opening. The technician weighs the cassette and filter together before and after sampling. Particulates collected on both the filter and walls of the cassette represent the inhalable mass fraction [14]. There are two challenges with using the IOM sampler: a scale with a sensitivity of at least 0.001 mg is necessary to obtain a sufficiently accurate mass of the cassette/filter combination and the IOM is relatively expensive. Sampling depainting and scarfing operations in closed-face mode will significantly underestimate worker exposures [15]. To reduce bias from sampler orientation, use a cassette holder designed to keep the cassette face parallel to the worker's body [16]. Use 5.0-µm PVC filters as the sampling media. Use a sampling flow rate of 2.0 lpm. Analyze the filters per NIOSH Method 0500, which requires pre- and post-weighing filters with a 0.001-mg sensitivity scale [17]. If such a scale is not available, then use match-weighted filters and submit for analysis.

3.3.3 Respirable Particulates. A respirable cyclone samples for respirable dust. The cyclone separates the larger particles from the aerosol size distribution, collecting the respirable mass on a filter. The most common cyclones in use are the MSA® nylon cyclone and the SKC® aluminum cyclone. These two cyclones are slightly different in design and require different flow rates to operate properly: 1.7 lpm for the MSA nylon cyclone and 2.5 lpm for the SKC aluminum cyclone [18]. Use a 5.0-µm PVC filter mounted in a 37-mm cassette attached to the cyclone. Analyze the filters per NIOSH Method 0600 [19], requiring pre- and post-weighing of filters or, in the absence of an adequate scale, match-weighted filters.

3.4 Data Evaluation

3.4.1 Process Timelines. Sample each composite repair procedure separately. Sample as many workers involved in each process as possible. Make sure the air sampling narrative includes a timeline during each procedure, specifically the time the workers actually perform the procedure (process duration). The process duration is not necessarily the time the sampling pumps were turned on and off, since workers tend to take breaks or do other work during the procedures.

3.4.2 ACM Exposure Calculation. Calculate both the process exposure and the 8-h TWA exposure. The process exposure is the average concentration over the length of the process and is useful for determining effectiveness of engineering controls and respiratory protection. For example, engineering controls that keep process exposures below the 8-h TWA exposure limit will protect the worker even if the worker performs an operation for an entire 8-hour workday. Use Equation 1 to calculate process exposures and Equation 2 to calculate the 8-h TWA exposures.

$$\text{Process Exposure} = \frac{(\text{milligrams of contaminant})(1000 \text{ liters per cubic meter})}{(\text{sampling rate in liters per minute})(\text{process duration in minutes})} \quad (1)$$

$$8 - \text{h TWA} = (\text{Process Exposure}) \frac{(\text{process duration in minutes})}{(480 \text{ minutes})} \quad (2)$$

4.0 FIBERGLASS REPAIR ACTIVITIES

4.1 Description of Fiberglass Material

Fiberglass is a composite material consisting of a reinforcing glass fiber and a resin. The fibers are the load-bearing elements, while the resin fills the voids and transfers the stress from fiber to fiber [7,8]. Fiberglass materials are used in aircraft where material strength and low material weight are required. The most common fiberglass composite system found on aircraft consists of a continuous filament glass fiber (referred to as E-glass) woven into a material cloth and held together with an epoxy resin system [20]. S-glass and quartz are other glass fibers with different compositions used to a lesser degree on aircraft. The fiberglass aircraft part may consist of a honeycomb core sandwiched between two laminates or a solid laminate of resin-impregnated fibers stacked to maximize material strength. Typical aircraft locations for fiberglass panels are electrical transparency applications (radomes, antennas, dielectric edges), wear strips, access panels, and other lightly loaded structures as well as interior panels and cockpit panels.

4.2 Description of Fiberglass Processes

Workers perform fiberglass repair operations on aircraft parts. These parts are usually removed from the aircraft and repaired in a composite repair or structural maintenance facility. Occasionally, technicians make the repairs while the parts are still on the aircraft. Fiberglass repair operations vary across the Air Force, as Structural Maintenance shops use different tools, techniques, and ventilation systems. The repair operations usually consist of the following sequential procedures, which are very similar to ACM repair procedures from section 3.2 [21-25]. Step-by-step descriptions of these processes can be found in T.O. 1-1-690, *General Advanced Composite Repair Processes Manual* [13].

4.2.1 Damage Assessment. Assessment of fiberglass composite material damage of parts identified for repair. The technician may identify the part for repair because of a nick, gouge, or cut in the painted surface or by a broken or missing piece of fiberglass material. Workers perform the assessment by visually inspecting the part and marking the area for repair using either a marker or masking tape. Instrumented inspection techniques such as x-ray, ultrasonics, shearography, or thermography are also used.

4.2.2 Sanding/Grinding. Mechanical removal of coatings and damaged fiberglass material from the surface of the aircraft part. This procedure removes the topcoat, primer, and a portion of the damaged fiberglass. Some workers may initially remove the topcoat and primer before mechanically abrading the fiberglass to get a better look at the damage. Most workers, however, abrade both the coatings and fiberglass material at the same time. Workers may sand/grind using a pneumatic rotary right angle grinder such as the Dotco®, a straight grinder, or a rotary dual-action orbital sander and attach 1-, 2-, and 3-inch grinding discs to the grinders, although 5 inches is the most common sanding disc size. The most common grit sizes used during sanding are 80 and 120, although workers may use different sizes of grits. Sanding through the topcoat into the primer releases inhalable and respirable particulates, including those that contain chromates. As the fiberglass composite material is sanded, inhalable and respirable particulates are generated, along with a very minimal number of glass fibers (referred to as synthetic vitreous fibers) [26,27]. The fiberglass particulates are composed of several different metallic oxides present within the original glass fiber, including silicon, calcium, boron, and aluminum [4].

4.2.3 Clean Wiping. Removal of dust, dirt, and oil from the sanded surface. Residual dust is present on the part after sanding/grinding. Workers remove the majority of the dust by brushing, then wipe a solvent on the part with a clean rag. Several different solvents are available, including methyl ethyl ketone, acetone, or isopropyl alcohol; the most commonly used is isopropyl alcohol. The procedure normally takes less than 10 minutes, but the time devoted to clean wiping depends on the size of the surface area the worker is cleaning. Worker exposures result from the vaporization of the solvent applied to the part, but are usually limited because of the brevity of the operation.

4.2.4 Core Repair. Rebuilding or filling in damaged areas of the honeycomb core material. If the core material is damaged, in addition to the overlaying laminate, the worker may need to fill in the existing core with an epoxy-based compound to improve its strength. Occasionally, the core material is damaged beyond repair and must be completely replaced. The worker replaces the core material by cutting a section from the damaged core and installing a new section of honeycomb material using an epoxy-potting compound. Worker skin exposures to unreacted epoxy and amine compounds may occur while the potting compound is mixed and applied.

4.2.5 Wet Lay-Up. Cutting and stacking of fiberglass cloth to form a laminate or patch. A resin, usually epoxy-based, is mixed with a hardener, usually amine-based. Workers pour this mixture on the fiberglass cloth then spread the mixture with a spatula. The fiberglass cloth material is then cut and stacked to form a laminate. The technician puts a vacuum bag into place over the laminate. The resin systems present a skin contact hazard to personnel from uncured epoxy and amine groups.

4.2.6 Curing. Solidifying the laminate by placing it under heat and pressure. Workers place the laminate under a vacuum bag to ensure uniform pressure is applied. The laminate cures on the aircraft part by the heat generated from heat lamps. There is little potential for exposures to personnel during curing because of the vacuum bagging technique.

4.3 Air Sampling Methodology

During fiberglass repair operations, workers face possible exposure to particulates, glass fibers, chromates, crystalline silica (quartz), solvent vapors, metallic oxides, and uncured epoxy and amine groups. This special report only focuses on the particulate and fiber hazards directly from the fiberglass; however, a comprehensive exposure assessment should evaluate the unique hazards associated with each of the processes during repair. Table 4 summarizes sampling recommendations.

Table 4. Recommended Sampling Methodology for Fiberglass Repair

Operation	Substance	Sampling Method	Sampling Media	Sampling Flowrate (lpm)
Depainting, Scarfing, Sanding, or Grinding Processes	PNOS, Inhalable	NIOSH 0500	Pre-weighed, 5.0-µm PVC filter, 37-mm cassette	2.0
	PNOS, Respirable	NIOSH 0600	Pre-weighed, 5.0-µm PVC filter, 37-mm cassette with cyclone	1.7 (nylon) 2.5 (aluminum)
	Glass Fibers	NIOSH 7400 "B Rules"	0.8-µm MCE filter, 25-mm cassette with anti-static cowl	2.0

Note: MCE = mixed cellulose ester.

4.3.1 Particulates. Particulates generated during fiberglass repair procedures vary in size and particulate mass distribution. There are four types of particulate distributions: the total aerosol mass, the inhalable particulate mass, the thoracic particulate mass, and the respirable particulate mass [4,5]. These distributions are based upon the aspiration and deposition characteristics of the human respiratory tract. The primary size distributions of interest during fiberglass repair are the inhalable and respirable mass distribution. The inhalable mass is the portion of the total aerosol mass the worker actually breathes into the respiratory tract, while the respirable mass is that portion of the total aerosol that ends up in the gas-exchange region of the lungs.

4.3.2 Inhalable Particulates. Three inhalable (≤ 100 µm aerodynamic diameter), aerosol samplers are widely available, including the IOM sampler, the button sampler, and the conical inhalable sampler. The IOM and button samplers are distributed by SKC, Inc., and the conical inhalable sampler is distributed by BGI, Inc. The IOM sampler is the most well known of these three samplers. The IOM sampler uses a 25-mm filter placed inside a removable cassette with a 15-mm opening. The technician weighs the cassette and filter together before and after sampling. Particulates collected on both the filter and walls of the cassette represent the

inhalable mass fraction [14]. There are two challenges with using the IOM sampler: a scale with a sensitivity of at least 0.001 mg is necessary to obtain a sufficiently accurate mass of the cassette/filter combination and the IOM is relatively expensive and is not reusable to analyze samples for metals. Sampling depainting and scarfing operations in closed-face mode will seriously underestimate worker exposures [15]. To reduce bias from sampler orientation, use a cassette holder designed to keep the cassette face parallel to the worker's body [16]. Use 5.0-µm PVC filters as the sampling media. Use a sampling flow rate of 2.0 lpm. Analyze the filters per NIOSH Method 0500, which requires pre- and post-weighing filters with a 0.001-mg sensitivity scale [17]. If such a scale is not available, then use match-weighted filters and submit for analysis.

4.3.3 Respirable Particulates. Workers should use a respirable cyclone to sample for respirable dust (≤ 4 µm aerodynamic diameter). The cyclone separates the larger particles from the aerosol size distribution, collecting the respirable mass on a filter. The most common cyclones in use are the MSA® nylon cyclone and the SKC® aluminum cyclone. These two cyclones are slightly different in design and require different flow rates to operate properly: 1.7 lpm for the MSA nylon cyclone and 2.5 lpm for the SKC aluminum cyclone [18]. Use a 5.0-µm PVC filter mounted in a 37-mm cassette attached to the cyclone. Analyze the filters per NIOSH Method 0600 [19], which requires pre- and post-weighing of filters or, in the absence of an adequate scale, match-weighted filters.

4.3.4 Synthetic Vitreous Fibers. Sample for glass fibers following NIOSH Method 7400 [28]. Use 0.8-µm MCE filters mounted in a 25-mm cassette with an anti-static cowl. The cowl causes spurious fibers, such as those from clothing, to adhere to the cassette, preventing them from depositing on the filter. Use a sampling flow rate of 2.0 lpm. On the sampling form, request NIOSH 7400 and specify fiberglass. Ensure the analysis is done under the alternate counting rules for non-asbestos fibers, designated as the B rules [29].

4.4 Data Evaluation

4.4.1 Process Timelines. Sample each fiberglass repair procedure separately. Sample as many workers involved in each process as possible. Make sure to include in the air sampling narrative of the timeline during each procedure, specifically the time the workers actually perform the procedure (process duration). The process duration is not necessarily the time the sampling pumps were turned on and off, since workers tend to take breaks or do other work during the procedures.

4.4.2 Exposure Calculations. Calculate both the process exposure and the 8-h TWA exposure. The process exposure is the average concentration over the duration of the process and is useful for determining effectiveness of engineering controls and respiratory protection. For example, engineering controls that keep process exposures below the 8-h TWA exposure limit will protect the worker, even if they perform an operation for an entire 8-hour workday. Use Equation 1 to calculate process exposures and Equation 2 to calculate the 8-h TWA exposures as shown previously in paragraph 3.4.2.

5.0 VENTILATION OF COMPOSITE REPAIR OPERATIONS

Repair technicians use some form of ventilation to accomplish ACM and fiberglass repairs. Installations may have ventilation systems that include crossflow sanding booths, handheld vacuum hoses, downdraft tables, moveable exhaust hoods with flexible ducting, and ventilated pneumatic tools (referred to as low volume-high velocity exhaust systems). The primary purpose of the ventilation system is to collect particulates generated during depainting/scarfing and sanding/grinding procedures [Hakim A, Warnock R. Advanced composites aerospace structures repair class; 1998] [7]. Of these five types of systems, surveys indicate that moveable exhaust hoods and ventilated tools used in conjunction with crossflow booths provide the best control of particulates generated during in-shop composite repair operations. For repair of parts installed on aircraft, ventilated tools are the most appropriate choice to capture graphite and metallic dusts and prevent them from contaminating other aircraft components.

5.1 Ventilation Systems

5.1.1 Crossflow Sanding Booths. Fiberglass repairs typically take place in crossflow sanding booths because most aircraft fiberglass parts are relatively large. Most crossflow sanding booths in the Air Force are essentially paint booths. There are, however, commercially available sanding booths designed specifically for composite repair. Sanding booths are not as effective at controlling particulates as downdraft tables, hand-held vacuum hoses, moveable exhaust hoods, and ventilated tools, which capture particulates at the source of generation. Workers frequently position themselves between the part being sanded/scarfed and the exhaust location, causing contaminants to pass through their breathing zone and increasing their exposures. Sanding booths can be effective in reducing exposures if used in conjunction with some of the other systems listed below. There are no current guidelines in the industrial hygiene literature on effective ventilation rates for crossflow sanding booths.

5.1.2 Hand-Held Vacuum Hoses. Workers occasionally hold a vacuum hose near the part being scarfed to collect particulates generated. The hose attaches to a vacuum equipped with a high-efficiency particulate air (HEPA) filter. This system is more effective than a crossflow sanding booth because it collects particulates closer to the point of generation, but can cause significant fatigue for the workers since workers are holding the hose in one hand and the pneumatic tool in the other. Holding the hose with the free hand also results in the workers' breathing zones being physically closer to the point of contaminant generation, increasing exposures. Hand-held vacuum hoses should have airflows similar to those for moveable exhaust hoods.

5.1.3 Downdraft Tables. Downdraft tables have grilles on the table surface through which particulates are drawn. Downdraft tables usually have back and side shields to enclose the operation as much as possible. Air is drawn by a fan through a filter bank and exhausted either into the same room the booth is in or to the outside of the building, depending on the design. Positioning of the part on the table can influence the ability to collect particulates, depending on the design of the table, because air velocities can vary widely across the table surface. Air velocities should be measured across the surface of the downdraft table. Take sufficient

measurements to estimate the average flow. For abrasive blasting rooms, use the following equation to determine the required volumetric flowrate per area of floor space for downdraft booths: Q = 60-100 flowrate (in cubic feet per minute, cfm) at actual condition divided by feet squared (acfm/ft^2) [0.30-0.50 am^3/s/m^2]. For crossflow booths, Q = 100 acfm/ft^2 [0.5 am^3/s/m^2]. The minimum duct velocity for the branch leading to the dust collector is 3500 feet per minute (fpm) for both crossflow and downdraft abrasive blasting booths [30].

5.1.4 Moveable Exhaust Hoods. Moveable exhaust hoods generally have flexible exhaust ducts connected to a relatively small exhaust hood. A hinged arm may support the hood to allow positioning of the hood near the source of dust generation. Ensure the hood is placed within a few inches of the work surface and positioned toward the direction particulates are being thrown. The effective maximum distance of the hood from the source varies depending on the type of hood (e.g., a flanged slot typically performs better than a hood without a flange) and the velocity of the particulates emitted. As a rule of thumb, the maximum capture distance should not be more than 1.5 times the duct diameter. Air velocities should be measured across the face of the exhaust hood. Workers should take sufficient measurements to estimate the average flow. A minimum volumetric airflow of 400 cfm with a minimum duct velocity of 4000 fpm is the recommendation [30].

5.1.5 Ventilated Pneumatic Tools. Ventilated sanders and grinders typically have a number of holes located in the rotary disc through which particulates are drawn. The tool may also have a ventilated shroud (or extractor hood) covering the disc. The tools attach via a hose to either a vacuum containing a HEPA filter or a central vacuum system located in the shop. Ensure the sandpaper the workers use is compatible with the sander; the sandpaper should have the same number of holes as the sander and the holes should be properly aligned. Some sanders come with locking discs, while others have adhesive on the back of the sandpaper. Locking discs ensure proper alignment of the sandpaper with the holes. Measure the air velocity at the holes and multiply by the area of the holes. If the tool has a shroud, measure velocities at several places around the shroud and multiply by the area through which the air is drawn, add this value to the airflow through the holes. Sanders should have a minimum duct velocity of 3500 fpm, [17.50 m/s], 4500 fpm [22.50 m/s] if material is wet or sticky; grinders should have a minimum duct velocity equal to 4000 fpm [20.00 m/s] [30]. A portable HEPA vacuum will, in most situations, provide ventilation rates much lower than recommended; a central vacuum system, if properly operating, will likely provide higher ventilation rates.

There is a potential for workers to tilt the sander away from the surface when finishing the surface. Breaking the vacuum seal allows dust to escape into the shop environment. When advanced engineering controls are needed to control exposure, pneumatically powered mechanical arms connected to pneumatic ventilated sanders can reduce the instance to break the vacuum seal to achieve the correct surface finish. Workers should use these types of devices to reduce the risks of repetitive stress and vibration-induced injuries.

5.2 Filtration Systems

Air cleaning devices are an integral part of the ventilation system. Air cleaning devices are divided into two basic categories: air filtration and dust collectors. Air filtration removes low dust concentrations. Filters are typically used in heating, ventilation, and air conditioning systems where dust concentrations seldom exceed 1.0 grams per thousand cubic feet of air. Dust collectors are designed to handle concentrations 100 to 20,000 times greater than from air filtration systems. Currently, there is no accepted standard for testing and/or expressing the "efficiency" of a dust collector. Two factors must always be considered: 1) mass emission rate (grains/ft^3) and 2) volumetric flow rate (ft^3/min). It is generally recognized that filters become increasingly efficient as dust accumulates; therefore, filters should be changed when resistance prevents adequate volumetric flow rate [30]. To ensure proper operation of the ventilation system, workers should routinely clean and/or change filters. Filter cleaning and change-out can be effectively monitored by use of pressure drop gauges (such as magnehelic gauges) or by establishing, a routine maintenance schedule based on hours of use. HEPA vacuums used with ventilated tools should have their collection bags frequently emptied.

6.0 PERSONAL PROTECTIVE EQUIPMENT AND ADMINISTRATIVE CONTROLS

6.1 Respiratory Protection

Respiratory protection is based on the unique hazard characterization conducted by the local BEF for each unique process of concern. However, in most situations, respirators are not required during clean wiping due to the brevity of the procedure. Generally, respirators are also not required during core repair and lay-up due to low volatility of the epoxy resins and amine hardeners. Measurements taken during this study indicate that respiratory protection may often be required during the process of depainting and sanding/grinding. However, this conclusion is based on the elevated chromate levels. This illustrates the need for comprehensive exposure assessments on the part of local BEF to fully characterize all the anticipated health hazards for each process. Additionally, observations of ACM repair indicate respiratory protection is often needed during scarfing. It was observed that the ventilation system used during some scarfing processes might not adequately collect all residual dust. It has been reported that during some scarfing and sanding/grinding processes, the smell from low-temperature thermal decomposition products generated during grinding makes workers uncomfortable [11]. An organic amine compound is likely the source of these odors. A HEPA filter will collect chromate particulates generated during depainting and sanding/grinding and inhalable dusts/fibers generated during scarfing [31]. An organic vapor (OV) cartridge will remove the thermal decomposition odor. Therefore, an air-purifying respirator (APR) with a combination HEPA/OV cartridge will, in most situations, provide workers adequate respiratory protection.

Using powered APRs (PAPRs) during depainting/scarfing and sanding/grinding provides an option for respiratory protection. PAPRs consist of a cartridge, blower, and battery pack that mount on the worker's belt. The worker receives air provided through a breathing tube fitted to either a tight-fitting face piece or a loose-fitting hood. A hooded PAPR has several benefits compared to either an APR or a PAPR with a tight-fitting face piece. Hooded PAPRs do not require either fit-testing or positive/negative seal (fit) checks before use, reducing workload for bioenvironmental engineers and training time for workers. Hoods provide a wider field of view and better peripheral vision and allow civilians to wear beards and glasses, thereby increasing

worker acceptance. Airflow into the hood provides cooling and makes it more comfortable to wear than tight-fitting face pieces in hot environments. There are no valves, straps, or rubber face pieces to inspect or wear out. Most hoods are disposable, reducing the time needed to clean the respirator. A hooded PAPR with a HEPA/OV cartridge may provide adequate protection during most in-shop and flightline fiberglass repair situations.

6.2 Hand Protection

Protective clothing and gloves are based on the unique hazard characterization conducted by the local BEF for each unique process of concern. In most cases, disposable nitrile rubber gloves provide adequate protection against particulates generated during depainting/scarfing and sanding/grinding as well as for many solvents used during clean wiping. For core repair and lay-up procedures, though, a special type of glove is often required. Many rubber gloves are made by a process called injection molding. Workers may treat the molds with a release agent, such as silicon, that allows the glove to be more easily removed from the mold. During lay-up procedures, if the release agent contacts either the resin system or the area where the resin system is to be applied, the laminate quality may be significantly reduced [Warnock R. Advanced Composite Program Office. Personal communication; 1998 Apr]. Additionally, any particulate within the glove, such as powder, will also reduce the quality of the composite patch, as the powder has a potential to contaminate the repair area. Comasec® manufactures cotton-lined latex gloves that do not contain any release agents that can be used during both core repair and wet lay-up [Hubble P. General Electric Corporation. Personal communication; 1998 Oct; Petrosky J. Comasec Incorporated. Personal communication; 1998 Oct]. When workers handle epoxy resins and amine hardeners, such as during core repair and wet lay-up, this report recommends that they wear disposable nitrile rubber gloves underneath the Comasec® gloves to provide added protection.

6.3 Other Protective Equipment

In most situations, workers should wear cotton or Tyvek® coveralls to reduce skin contact and reduce the spread of workplace contamination from the sanding dust. Disposable coveralls are preferred because they can be discarded after use; reusable cotton coveralls require laundering, which can lead to exposures to laundry personnel. Workers may require hearing protection during depainting and scarfing. This report recommends performing hazardous noise assessments for processes to determine if hearing protection is necessary. Workers must wear safety glasses if they do not wear a hooded or tight-fitting full-face piece respirator during these operations. Workers must wear safety toe boots during all composite repair procedures due to the potential for heavy aircraft parts and objects falling on the floor.

6.4 Workplace Practices

6.4.1 Control of Sanding Dust. Sanding of composite materials often generates dust. However, the need for controlling composite dusts is usually secondary to the need for controlling exposure to chromate paint dust. Due to chromates' carcinogenic potential, all dusts generated from sanding chromate paint should be contained within a designated portion of the composite repair facility. The main concern is transfer of dust into administrative areas, break rooms, and other

areas where personnel not directly involved in the procedure may receive incidental exposures to chromates or other hazardous particulates. It is particularly important that workers do not bring chromate-containing dusts home on their clothing and expose family members. The ideal setup would include a controlled entrance/exit to the depainting/scarfing or sanding/grinding area, changing area, shower facility, and dressing area. Realizing the ideal setup seldom exists in the Air Force, as a minimum, designate a dedicated entrance and exit to the sanding area. Workers shall remove or HEPA vacuum their coveralls prior to exiting the depainting/scarfing or sanding/grinding areas, whether that is a booth, room, or designated area. Personnel not involved with the operations should not enter the area without proper protective equipment. Those who work in areas where the airborne exposure is above the OEEL, without regard to the use of respirators, shall have shower facilities or other suitable decontamination available [32].

6.4.2 Dust Removal. According to 29 CFR 1910.1026(j)(2)(iii), "The employer shall not allow compressed air to be used to remove chromium (VI) from any surface" [33]. Also, dry sweeping of dust to clean up work areas that contain chromium is also a potential violation of 29 CFR 1910.1026(j)(ii). Therefore, before clean wiping with a solvent, workers should remove dust generated during depainting/scarfing and sanding/grinding activities with a HEPA vacuum. HEPA vacuums remove chromium dusts effectively and with less exposure to personnel than compressed air or dry sweeping. This would apply to potential cadmium [29 CFR 1910.1027(i)(3)(iii)] and lead [29 CFR 1910.1025(g)(2)(viii)] as well.

6.4.3 Venting of Curing Procedure. Composite parts may be cured in an oven or autoclave. This equipment vents to the exterior of the building whenever possible to prevent worker exposures to curing vapors. If workers use the vacuum bagging technique, vent the central vacuum system to the exterior of the building if possible.

6.4.4 Limit Personnel Exposed. When depainting/scarfing or sanding/grinding, only one worker should mechanically abrade the aircraft part at a time. If several composite repair operations are occurring in the composite repair facility, position the parts so dust generated by one operation does not pass into another worker's breathing zone.

7.0 AIRCRAFT BATTLE DAMAGE REPAIR

7.1 Process Description

Aircraft battle damage is most frequently caused by projectiles and usually results in holes surrounded by jagged edges, cracks, and tears. Workers remove this damage by drilling, grinding, or cutting away the damaged material [34]. ABDR operations encompass all structural and system repairs necessary to repair this damage and restore the aircraft to flying status. ABDR is governed by T.O. 1-1H-39, *Aircraft Battle Damage Repair, General*, and by weapon system specific 39 series technical orders. AFTO Form 97, *Aerospace Vehicle Battle Damage Repair Debrief Assessment Record*, is used to record repairs accomplished on aircraft [available at Air Force e-Publishing/Forms: http://www.e-publishing.af.mil/]. Combat Logistics Support Squadron (CLSS) and Air Force Special Operations Command (AFSOC) personnel perform ABDR operations at fixed air bases or in remote locations where aircraft have been damaged.

During ABDR operations, workers may perform composite repair on aircraft parts remaining on the aircraft. Damage to composite structures will often consist of a splintered hole surrounded by delamination and ply peeling [Boeing Information, Space, and Defense Systems Group. Subject: Aircraft battle damage repair of composite structures; 1998 Jun 30]. Workers use mechanically fastened aluminum or stainless steel patches to repair composite material damage, or repair the composite material damage using the sequential procedures described in either this special report or aircraft manufacturers' literature. ABDR composite material maintenance operations will also vary somewhat across the Air Force depending on the aircraft under repair. CLSS and AFSOC squadrons maintain mobile trailers for ABDR training equipment and supplies. Many of these trailers are pre-positioned at various locations around the world to support maintenance operations in the event of a wartime contingency. A trailer is brought to the site or the installation where the aircraft repairs are needed. There is a limited amount of supply and equipment storage space within the ABDR trailers [Mason C. ABDR Program Management Office. Personal communication; 1999 Feb].

ABDR operations will usually take place in environments without CBRN contamination. In uncontaminated environments, workers should wear the same PPE as during in-shop composite material repairs [Mason C. ABDR Program Management Office. Personal communication; 1999 Feb]. ABDR operations, however, may take place in areas under the threat of CBRN contamination. To prepare for contingencies involving CBRN contamination, workers practice ABDR operations using the Joint Service Lightweight Integrated Suit Technology (JSLIST) and the Joint Service General Purpose Mask (JSGPM) M-50 protective mask. Workers may train for ABDR operations in environments both with and without CBRN contamination during base-wide or local exercises.

7.2 Air Sampling and Data Evaluation

Air sampling requirements and data interpretation for ABDR operations are the same as those described for ACM repair in sections 3.3 and 3.4 and fiberglass repair in sections 4.3 and 4.4 of this special report.

7.3 ABDR in Peacetime and Uncontaminated Wartime Environments

The recommendations for engineering controls and PPE for ABDR during peacetime and uncontaminated wartime environments are identical to those found in sections 5.0 and 6.0 above.

7.4 ABDR during CBRN Training Scenarios

7.4.1 Ventilation Systems. Although ventilated tools have been shown to reduce worker exposures to contaminants during composite repair (see Appendix A), they are not appropriate for use in a real world CBRN environment. If the vacuum mechanism of ventilated tools becomes contaminated with radioactive particulates or chemical/biological agents, it would be virtually impossible to decontaminate. Local leadership will need to conduct a cost/benefit analysis as to whether mission accomplishment outweighs contaminating ventilated tools if a real world CBRN threat arose.

7.4.2 Respiratory Protection. The recommended respiratory protection for ABDR in CBRN training scenarios is the same respiratory protection that is required per local BEF's health hazard evaluation as during normal peacetime operations. The JSGPM M-50 is not authorized for use as a substitute for the approved occupational respiratory protection during training events. However, for processes that do not normally require respiratory protection for the occupational control of a hazard, then the JSGPM M-50 protective mask may be worn during training exercises as dictated by local CBRN training requirements.

7.4.3 Hand Protection. The butyl rubber protective gloves worn as part of the ground crew ensemble provide adequate protection against the particulates and chemicals encountered during composite repair operations [35].

7.4.4 Other Protective Equipment. The JSLIST reduces skin contact with sanding dust and provides protection to personnel from particulates and chemicals encountered during ABDR training exercises. The ground crew ensemble should be HEPA vacuumed after training use to remove particulates. The ground crew ensemble should also be washed after training use to remove any particulates remaining on the garment.

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APPENDIX A: ADVANCED COMPOSITE MATERIAL REPAIR FIELD STUDY RESULTS

SURVEY LOCATIONS

A major part of evaluations involved determining the effectiveness of various ventilation systems to control exposures during advanced composite repair operations. Field studies were done at Charleston, Robins, and Hill AFBs and the Structural Maintenance School at Pensacola Naval Air Station. The Advanced Composite Support Office suggested these locations based on the various types of ventilation systems in use. In addition, the ACSO set up a field experiment at McClellan AFB to perform controlled comparisons between different ventilation systems.

FIELD STUDIES

Systems Evaluated

The following ventilation systems were in use during scarfing at the field sites: moveable exhaust hoods with flexible ducting, hand-held vacuum hoses, and crossflow sanding booths.

Results

Worker exposures to respirable dust and fibers during scarfing, using the three different ventilation systems, are summarized in Tables A-1 and A-2. Means were determined from Land's procedure for calculating exact confidence intervals around the mean of log-normally distributed data [A-1]. Overall exposures were lowest with the moveable hood.

Table A-1. Respirable Dust Exposures during Scarfing (Process Exposures)

Ventilation System	No. of Samples	Range (mg/m^3)	Mean (mg/m^3)
Moveable exhaust hood	10	0.053 – 0.777	0.295
Hand-held vacuum hose	3	0.717 – 11.78	4.642
Crossflow booth	2	0.847 – 0.964	0.906

Table A-2. Fiber Exposures during Scarfing (Process Exposures)

Ventilation System	No. of Samples	Range (f/cc)	Mean (f/cc)
Moveable exhaust hood	9	0.001 – 0.030	0.018
Hand-held vacuum hose	3	0.026 – 0.153	0.074
Crossflow booth	2	0.004 – 0.184	0.094

Discussion

Each ventilation system has certain disadvantages that workers should consider when evaluating them. The moveable exhaust hood visually appears to collect dust better than the other two systems, but must be positioned within a few inches of the work surface to effectively remove particulates. Workers have to hold the vacuum hose with one hand while grinding with the other. This positioning results in the workers' breathing zones being physically closer to the point of contaminant generation, thereby increasing exposures. The crossflow booth offers a

large space for personnel to work in. Unfortunately, workers position themselves so dust generated from other composite operations taking place in the booth passes through their work areas and breathing zones before being exhausted. This positioning probably results in greater worker exposures than if only one worker was scarfing in the booth. In addition to these three systems, scarfing procedures on a downdraft table were also observed (sampling data not available). The system visually does not appear to be very effective at controlling particulates, but this may be because the filters needed cleaning, which may reduce the available airflow.

Conclusions

Field studies conducted by ACSO indicated that among the systems tested, a moveable exhaust hood with flexible ducting provides the best control of contaminants generated during in-shop advanced composite material repair operations.

MCCLELLAN AFB FIELD EXPERIMENT

Systems Evaluated

An experienced structural maintenance technician performs ACM depainting and scarfing processes. Having only one worker accomplish the processes reduces between-worker variability. The processes are accomplished at the same composite repair facility and on the same work bench.

Depainting

Two aircraft part depainting processes were monitored. The worker first sands using an unventilated pneumatic dual action rotary sander, then sands with a ventilated pneumatic dual action rotary sander. Breathing zone air samples for inhalable dust, respirable dust, and hexavalent chromium were collected during the depainting processes. Table A-3 presents the results. During both processes and for all contaminants measured, process exposures are less when using the ventilated sander.

Table A-3. Comparison of Process Exposures during Depainting

Depaint Tool	Inhalable Dust (mg/m^3)		Respirable Dust (mg/m^3)		Hexavalent Chromium (mg/m^3)	
	Process 1	Process 2	Process 1	Process 2	Process 1	Process 2
Unventilated sander	15.59	11.60	4.56	8.78	0.059	0.046
Ventilated sander	4.34	0.049	1.84	1.03	0.008	0.013

Scarfing

The worker scarves 6-inch-diameter patches on three types of composite material. Scarfing takes place in a crossflow sanding booth. The worker uses three combinations of commonly encountered work tools and ventilation systems: an unventilated right angle grinder, a ventilated right angle grinder, and a right angle grinder in combination with a vacuum hose held by the worker. Each of the three combinations is monitored with the crossflow both on and off, for a

total of six different variations. Air samples for inhalable dust, respirable dust, and fibers are collected. Table A-4 displays the results. In one case, no weight change is noted on the filter and the result is indicated as "ND." Some of the fiber results are reported as "OL" or overloaded. The lowest process exposures found are indicated by boldface type. Overall, process exposures were lowest when using the ventilated grinder as compared to using the crossflow booth by itself or the hand-held vacuum hose.

Table A-4. Comparison of Process Exposures during Scarfing

Ventilation System	Inhalable Dust (mg/m^3)			Respirable Dust (mg/m^3)			Fibers (f/cc)		
	Gra/Kev	**Graphite**	**Fiberglass**	**Gra/Kev**	**Graphite**	**Fiberglass**	**Gra/Kev**	**Graphite**	**Fiberglass**
None	8.350	27.429	9.378	9.977	0.419	1.313	OL[a]	OL[a]	OL[a]
Crossflow booth	3.569	4.607	3.95	1.992	0.389	3.5	0.0475	OL[a]	0.0079
Hand-held vacuum hose	5.708	16.684	2.491	2.623	3.261	2.016	0.0736	OL[a]	0.004
Vacuum hose w/crossflow booth	2.265	8.045	ND[b]	0.226	0.311	1.216	0.1206	0.143	0.0158
Ventilated grinder	0.677	0.83	1.351	0.734	0.801	4.032	0.0241	0.0998	0.0041
Ventilated grinder w/crossflow booth	0.779	8.97	0.59	0.649	1.489	0.465	0.0041	0.0079	0.0039

[a]Filter overloaded.
[b]None detected.

Discussion

The depainting results clearly show the ventilated sander reduced worker exposures. Although the scarfing procedures are not sampled enough to make a valid statistical comparison, the data indicate that all the ventilation systems tested reduced worker exposures. Of the three ventilation systems tested, the results suggest that the ventilated grinder reduce exposures the most, although additional sampling results are needed to confirm this. Two of the respirable dust results are lower for the vacuum hose than for the ventilated grinder. This disparity may be explained in part by worker positioning. When holding the vacuum hose, the worker moves around a lot due to fatigue. This movement shifts his position in relation to the work surface and also shifts the location of the cyclone sampler attached to his coveralls. The worker's frequent repositioning may also shift the orientation of the cyclone aerosol inlet, resulting in the lower readings found.

Conclusions

The McClellan AFB field experiment report concludes the following:

1. Ventilated sanders effectively reduce worker exposures during depainting procedures.
2. Ventilated grinders and hand-held vacuum hoses are more effective than crossflow booths during scarfing procedures, probably because they capture contaminants at the point of generation.

REFERENCE

A-1. Hewett P, Ganser GH. Simple procedures for calculatating confidence intervals around the sample mean and exceedance fraction derived from lognormally distributed data. Appl Occup Environm Hyg 1997; 12(2):132-42.

APPENDIX B: FIBERGLASS FIELD STUDY RESULTS

SURVEY LOCATIONS

Several installations are visited for field studies. They include Robins, Hurlburt, Eglin, Hill, and McClellan AFBs and the Cherry Point Naval Aviation Depot. The ACSO suggests these locations based on the various types of ventilation systems and PPE in use.

RESULTS

Tables B-1 and B-2 summarize the results of the fieldwork. These tables also present process exposure and 8-h TWA exposure data for fiberglass sanding/grinding processes, respectively. Means and 95% confidence limits are determined from Land's procedure for calculating exact confidence intervals around the mean of log-normally distributed data [A-1]. At installations where the workers use no ventilation during fiberglass repair, we observe large amounts of sanding dust on the floors, tables, and the workers.

Note: the original 1999 report did not include a discussion or conclusion section in this appendix.

Table B-1. Exposures during Sanding/Grinding (Process Exposures)

Substance	No. of Samples	Range	Mean	95% Confidence Limits
Inhalable Particulate[a]	24	0.083 – 26.31	3.837	(2.497, 8.363)
Fibers[b]	16	0.011 – 0.309	0.073	(0.049, 0.156)

[a]Units mg/m^3.
[b]Units f/cc.

Table B-2. Exposures during Sanding/Grinding (8-h TWA Exposures)

Substance	No. of Samples	Range	Mean	95% Confidence Limits
Inhalable Particulate[a]	24	0.017 – 2.476	0.362	(0.229, 0.857)
Fibers[b]	16	0.001 – 0.013	0.006	(0.004, 0.012)

[a]Units $mg/m^{3.}$
[b]Units f/cc.

APPENDIX C: ABDR FIELD STUDY RESULTS

Field studies during ABDR operations were accomplished at Tinker, McClellan, and Hill AFBs. Monitored ABDR operations are considered representative of ABDR composite repair operations performed throughout the Air Force. Table C-1 presents the sampling results from these ABDR field studies. Process exposures were below their respective 8-h TWA USAFSAM recommended OEELs, OSHA PELs, and USAFSAM exposure guidelines for substance fibers without exposure standards for fibers and particulates [4,5,C-1,C-2]. Process exposures during ABDR were generally higher than those found during in-shop advanced composite material repairs, probably because ventilation systems were not in use.

Note: the original 1999 report did include separate sections regarding results, a discussion, or a conclusion in this appendix. The exposure table is provided for the reader's historical consideration.

Table C-1. Worker Process Exposures during Aircraft Battle Damage Repair

Base	Operation	Worker No.	Process Time (min)	Particulates (mg/m^3)			Fibers (f/cc)
				Inhalable	Respirable	Chromium VI	
Tinker	Depainting/scarfing F-16 stabilizer	1 2	53 44	4.545 5.962	2.375 2.776	0.00157 0.00066	0.0502 0.0248
	Depainting/scarfing F-16 stabilizer	1 2	29 29	2.136 3.489	2.796 2.025	0.00100 0.00139	0.0044 0.0333
	Depainting/scarfing F-16 stabilizer with weather enclosure	1 2	47 47	8.167 6.974	3.191 2.088	0.00249 0.00177	0.0051 0.0027
McClellan	Scarfing simulated aircraft section	3	60	1.953	<0.20	--	0.0019
	Scarfing simulated aircraft section	3	60	2.371	0.532	--	0.0007
Hill	Depainting/scarfing F-16 stabilizer	4 5	38 38	6.554 0.234	<0.48 <0.55	0.00973 0.00266	0.0221 0.0563

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C-1. Wright MT, Darwin RL, Scheffey JL, Bowman HL, Davidson RA, et al. Composite materials in aircraft mishaps involving fire: a literature review. China Lake, CA; Naval Air Warfare Center Weapons Division; 2003 Jun. Report No. NAWCWD TP 8552. Retrieved 1 May 2014 from www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA420193.

C-2. Kasting C, McCullough J, Kiefer M. U.S. Airways/Charlotte Aircraft Support Center Charlotte, North Carolina. Cincinnati, OH: National Institute for Occupational Safety and Health; 2000. NIOSH Health Hazard Evaluation Report HETA 99-0342-2821.

LIST OF ABBREVIATIONS AND ACRONYMS

ABDR	aircraft battle damage repair
ACGIH	American Conference of Governmental Industrial Hygienists
ACM	advanced composite material
ACSO	Advanced Composites Support Office
AFB	Air Force Base
AFSOC	Air Force Special Operations Command
APR	air-purifying respirator
BEF	Bioenvironmental Engineer Flight
CBRN	chemical, biological, radiological, and nuclear
cfm	cubic feet per minute
CLSS	Combat Logistics Support Squadron
ESOH	environmental, safety, and occupational health
f/cc	fibers per cubic centimeter
fpm	feet per minute
HEPA	high efficiency particulate air
IERA	Air Force Institute for ESOH Risk Analysis
IOM	Institute of Occupational Medicine
JSGPM	Joint Service General Purpose Mask
JSLIST	Joint Service Lightweight Integrated Suit Technology
lpm	liters per minute
MCE	mixed-cellulose ester
mg/m^3	milligrams per meters cubed
NIOSH	National Institute for Occupational Safety and Health
OEC	Consultative Services Division
OEEL	occupational and environmental exposure limit
OSHA	Occupational Safety and Health Administration
OV	organic vapor
PAPR	powered air-purifying respirator
PEL	permissible exposure limit
PNOS	particles not otherwise specified
PPE	personal protective equipment
PVC	polyvinyl chloride
TLV	threshold limit value
T.O.	Technical Order
TWA	time-weighted average
USAFSAM	U.S. Air Force School of Aerospace Medicine